Technology Maturation with **NASA Flight Opportunities**

Freeze Casting Metallic and Ceramic Foams in Microgravity

Parabolic flights helped mature Northwestern University's process for space-based manufacturing

Freeze casting in microgravity is a novel materials-processing technique with the potential to provide scalable, affordable in-space manufacturing of materials and structures. Numerous advantages for space exploration include reduced launch costs and enabling transport of raw materials to build structures that would otherwise be too large to launch.

To better understand the properties of titanium (metal) foams and titanium-oxide (ceramic) foams resulting from freeze casting, scientists at Northwestern University have taken advantage of parabolic flight testing through Flight Opportunities, maturing their process and putting it in the queue for a 6-month CubeSat mission in orbit.

> *"What we've learned through the Flight Opportunities program testing has put us in a position to better design our experiment for the CubeSat. In the two years we spent with the program, we were able to continue to improve our process and understanding—and that puts us in a much better position to actually succeed with the CubeSat testing."*
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> — David Dunand, James N. and Margie Krebs Professor of Materials Science and Engineering, Northwestern University

Northwestern University student researchers (from left to right) Felicia Teller and Amelia Plunk and Bryce Tappan of Los Alamos National Laboratory work with the freeze casting process during a test flight. Photo credit: NASA

Maturation Milestones

Notable test flights through Flight Opportunities have aided Northwestern scientists' understanding of the titanium-based foams resulting from their freeze casting process in microgravity:

- **A series of parabolic flight tests** in July 2014 enabled scientists to test whether gravity affected the structure of freeze-cast ceramic foams.
- **A second round of parabolic flights** in June 2015 helped scientists further understand the effects of convective fluid motion on freeze-cast metallic foams.

Benefits of Flight Opportunities

Flight Opportunities advances the operational readiness of innovative space technologies through affordable access to relevant test environments. Specific benefits for the Northwestern University freeze-casting process included:

- **Understanding the effects of gravity:** Working with a complicated process that is new to the space community and not fully understood, scientists used the parabolic flights to determine the significant effect of gravity on the foams created by their freeze-casting process.
- **Refining understanding of the materials:** Multiple flights allowed investigators to iteratively examine various effects on the foams, including convective fluid motion, sedimentation, and different levels of metallic solids.
- **Increasing TRL:** Refinements and improvements to Northwestern's freeze-casting process have increased the technology readiness level (TRL) from 4 to 6, aiding in its selection for an upcoming CubeSat mission.

About the Technology

An emerging field of research, the creation of metallic and ceramic foams via freeze casting is of particular interest to aerospace engineers. Titanium resists corrosion and has a high strength-to-weight ratio, and both titanium and titanium-oxide foams are lightweight and have high structural integrity. Foams based on titanium could be used to improve space-based manufacturing, while titanium-oxide structures could be applied to dye-sensitized solar cell electrodes, filtration, and wastewater decontamination.

Researchers surmised that terrestrial-based gravitational forces result in inferior titanium and titanium-oxide foams and that those created in microgravity-based freeze casting would have better pore alignment and order. Northwestern University's flight tests aimed to verify this assumption.

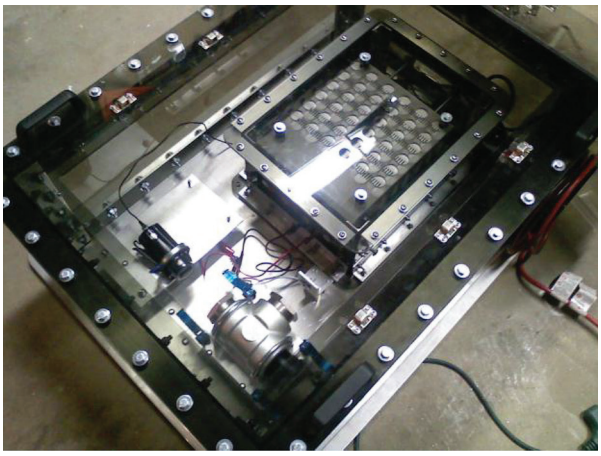
Overcoming Challenges

Working with a technology that is not widely understood, researchers needed to examine whether—and to what extent—gravity might be a factor. Laboratory tests gave them reasonable evidence both for and against a significant gravitational influence, so testing in microgravity was critical to answering this challenging question.

The 2014 flight tests revealed that gravity had a substantial impact on the freeze casting results. Structures created in near space indeed exhibited far more desirable properties than those created on Earth. Subsequent testing in 2015 allowed the researchers to isolate other factors, such as convective fluid motion and sedimentation of particles in the titanium and titanium-oxide foams. Combining these observations helped them better understand the material's properties in order to improve their process for longer duration testing.

Looking Ahead

Northwestern University's work with Flight Opportunities has increased the process's TRL to 6, which aided in its selection for a 6-month NASA CubeSat mission. It has also been selected under the NASA Materials Lab Open Science Campaign for an International Space Station demonstration with an anticipated launch in 2019 or 2020.



The freeze-casting apparatus consists of a polycarbonate box, which houses a power supply, camera, and sample chamber. Photo credit: Northwestern University

Learn More

For more information about the metallic and ceramic foam technology and freeze casting in microgravity process, visit: **spaceice.org**

For more information about NASA's Flight Opportunities program, visit: **www.nasa.gov/flightopportunities**